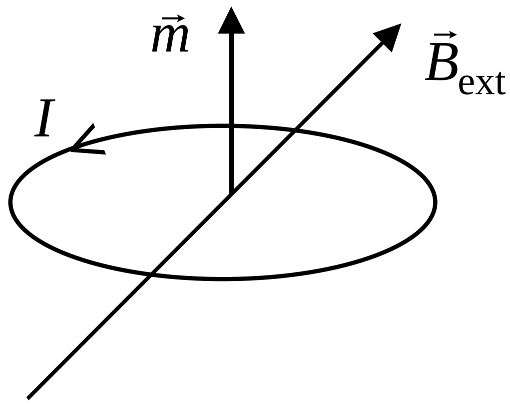
Nature of Magnetic Materials (1)

- Accurate quantitative analysis requires quantum mechanics
- Simple atomic model: orbiting electrons are small current loops
- The magnetic moment is caused by:
  1. electron orbit (electron orbiting the nucleus)
  2. electron spin (electron spinning about its axis)
  3. nuclear spin (nucleus spinning about its axis – weak effect)



- An external magnetic field $\vec{B}_{\text{ext}}$ puts a torque on the atomic loops causing the dipoles to align with or against the external field
- Broad classification of the magnetic properties of materials:
  1. diamagnetic, small negative χ_m
  2. paramagnetic, small positive χ_m
  3. ferromagnetic, large positive χ_m

Nature of Magnetic Materials (2)

- Diamagnetic Materials

  1. When $\vec{B}_{\text{ext}} = 0$ the net magnetic moment is zero (the spin and orbit components cancel)
  2. When $\vec{B}_{\text{ext}} \neq 0$ there is a small net magnetic moment induced in a direction opposite to $\vec{B}_{\text{ext}}$ (negative χ_m, $\mu_r < 1$ but close to 1)
  3. When $\vec{B}_{\text{ext}}$ is removed no magnetization remains

- Paramagnetic Materials

  1. Spin and orbit components do not completely cancel, but the net $\vec{m}$ from atom to atom is randomized due to thermal agitation (thus paramagnetism is temperature dependent)
  2. When $\vec{B}_{\text{ext}} \neq 0$ the dipoles align themselves with $\vec{B}_{\text{ext}}$ (positive χ_m, $\mu_r > 1$ but close to 1)
  3. When $\vec{B}_{\text{ext}}$ is removed almost no magnetization remains

Nature of Magnetic Materials (3)

- Ferromagnetic Materials

  1. Large dipole moments are due to electron spin
  2. Groups of adjacent atoms (domains) have dipole moments similarly aligned.
  3. The alignment of the domains can be random (therefore no magnetization) until $\vec{B}_{\text{ext}}$ is applied
  4. When $\vec{B}_{\text{ext}}$ is removed a net magnetization remains

- Other categories:

  <u>Ferrimagnetism</u>: Similar to ferromagnetism, except that the domains are anti-parallel and don't quite cancel
  <u>Anti-ferrimagnetism</u>: The domains are anti-parallel and completely cancel

Summary of Magnetic Materials

Type of Magnetism	Applied External Magnetic Field	External Magnetic Field Removed	
Diamagnetism	$\vec{B}_{\text{ext}}$		No $\vec{M}$ remains
Paramagnetism	$\vec{B}_{\text{ext}}$		No $\vec{M}$ remains
Ferromagnetism	$\vec{B}_{\text{ext}}$		Large $\vec{M}$ remains
Ferrimagnetism	$\vec{B}_{\text{ext}}$		Small $\vec{M}$ remains
Anti-ferrimagnetism	$\vec{B}_{\text{ext}}$		No $\vec{M}$ remains